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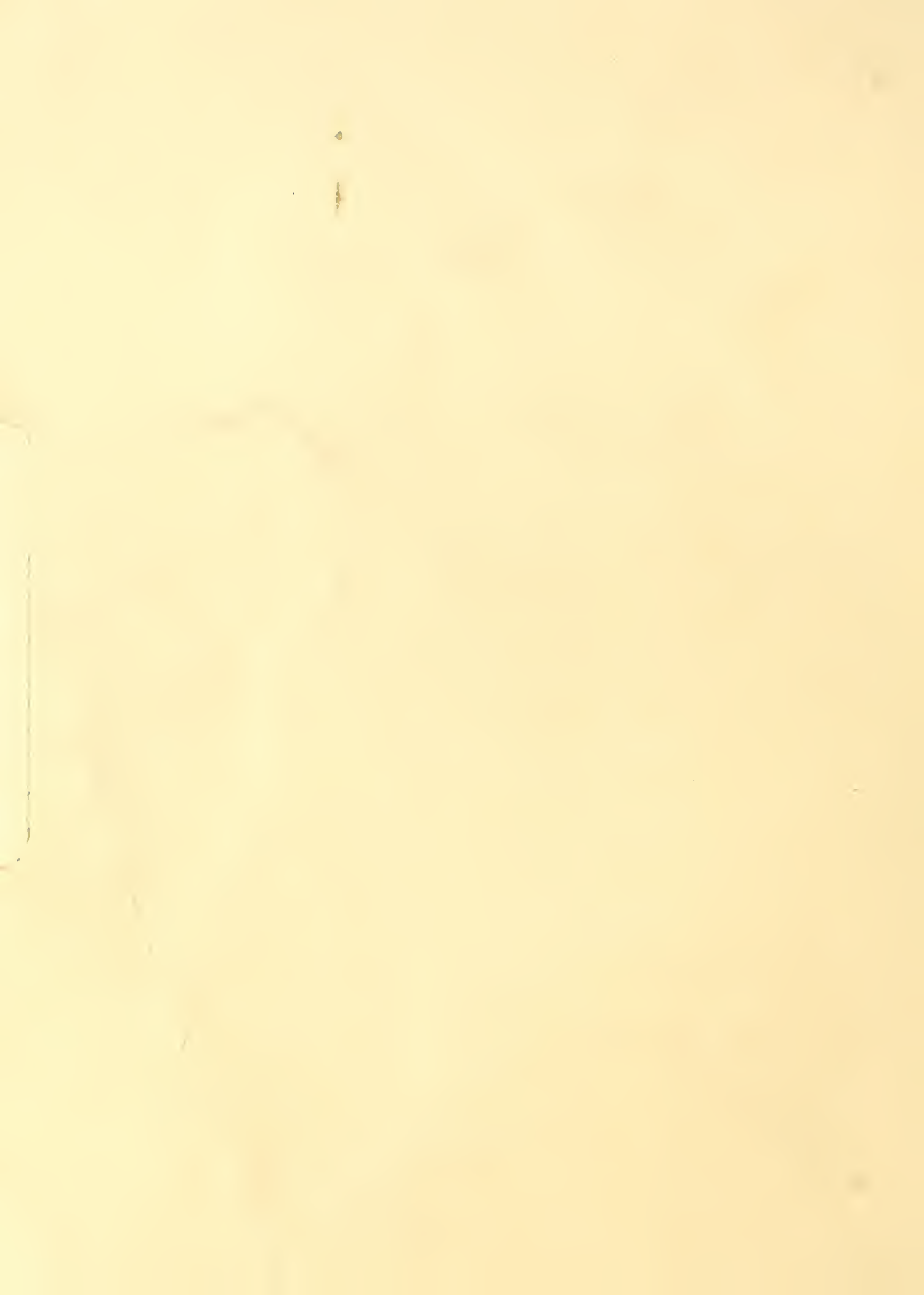
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Lodgepole Pine Vigor, Regeneration, and Infestation by Mountain Pine Beetle Following Partial Cutting on the Shoshone National Forest, Wyoming

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RESEARCH SUMMARY

Lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) stands were thinned in the Shoshone National Forest of northwestern Wyoming in 1979 and 1980 using different forms of partial cutting to determine if losses to mountain pine beetles (*Dendroctonus ponderosae* Hopkins) could be reduced by such treatment. Forms of partial cutting used were (1) remove all trees ≥7 inches diameter at breast height (d.b.h.); (2) remove all trees ≥10 inches d.b.h.; (3) remove all trees ≥12 inches d.b.h.; (4) spaced thinnings that kept about 50 of the best trees; and (5) no cutting. Average losses of trees 5 inches d.b.h. and larger during the 5 years following thinning ranged from less than 1 percent in the spaced thinnings to 7.4 percent in the 12-inch diameter limit cut, compared to 26.5 percent in check stands. Regeneration 5 years after thinning ranged between 1,160 and 3,560 seedlings per acre, with pine being favored in the more open stands. Residual trees increased radial growth significantly during the first 5 years following thinning. However, many trees should have remained susceptible to mountain pine beetle infestation because of large diameter and low growth efficiency. Changes in microclimate of thinned stands are suspected of affecting beetle behavior and hence of reducing numbers of infested trees.

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INTRODUCTION

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (MPB) continues to kill millions of lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) annually in the Western United States and Western Canada. In terms of trees killed by forest insects, MPB frequently ranks at the top of the list and is the foremost tree killer of lodgepole pine (Loomis and others 1985; Sterner and Davidson 1982).

Until about 1970, the principal way of treating MPB infestations was through direct control, consisting of applying insecticide to infested trees or felling and burning infested trees (Klein 1978; Safranyik and others 1974). At best, these proved to be short-term holding actions until trees could be harvested. Generally, unless susceptible trees are harvested immediately, MPB infestations will continue in stands treated with insecticides, and within a few years losses are such that remaining timber cannot be harvested economically (Amman and Baker 1972). Harvesting susceptible trees or modifying stand conditions that are conducive to MPB infestation (McGregor and others 1987) are the only long-term solutions to the MPB problem. Therefore, silvicultural methods that are preventive in their action should be emphasized.

Clearcutting may be the preferred silvicultural option for the majority of high-risk lodgepole pine stands in a specific drainage. However, concern for other resource values (namely, riparian areas, wildlife hiding, thermal and escape cover, watershed protection, and view areas) limits the amount of clearcutting and frequently permits only partial treatment of many susceptible stands (Bollenbacher and Gibson 1986). These concerns lead managers to ask for other options that might reduce stand susceptibility to the beetle, yet be compatible with management of other resource values. Partial cutting (Alexander 1986) offers promise for meeting these objectives.

Partial cutting to reduce losses of lodgepole pine to MPB was first tested in Colorado in 1972 (Cahill 1978). Treatment consisted of removing large-diameter trees to

which MPB is attracted (Shepherd 1966). The thicker phloem (food for developing larvae) in larger trees usually results in high beetle production (Amman 1972). The partial cuts resulted in minimal tree losses to MPB (1 to 2 percent), compared to losses in unthinned stands (>30 percent).

Subsequent to the Colorado work, four partial cutting treatments were tested near West Yellowstone, MT (Hamel 1978). In three treatments, all trees larger than three specific diameter at breast height (d.b.h.) limits were removed: ≥7 inches and larger, ≥10 inches and larger, and ≥12 inches and larger. The fourth treatment was based on phloem thickness, where all trees having phloem ≥0.1 inch were removed. Compared to check stands, tree mortality was much less in partial cuts based on diameter limits but was about the same when cutting was based on phloem thickness.

Another form of partial cutting, consisting of spacing to leave residual basal areas (BA) of 80, 100, and 120 ft²/acre was studied along with diameter limit cuts starting in 1976 in the Kootenai and Lolo National Forests, MT. Losses of trees 5 inches and larger d.b.h. ranged from 4.0 to 38.6 percent in the Kootenai and 6.0 to 17.1 percent in the Lolo, compared to 93.8 and 73.1 percent, respectively, in check stands. Only the 120-ft² BA/acre treatment had large losses (38.6 percent) (McGregor and others 1987). In addition to diameter limit cuts, another form of partial cutting consisting of spaced thinnings leaving the best trees in the stands was studied on the Shoshone National Forest, WY (Cole and others 1983). Although tree mortality remained low 1 year after all thinnings were completed, tree losses were greater in check than in partial cut stands (Cole and others 1983), but a longer period of beetle pressure was necessary for differences among treatments to be manifested.

This paper reports on the first 5 years' results of the Shoshone study. The principal objective of this study was to test the effectiveness of partial cutting for reducing losses to MPB in the Shoshone National Forest, where lodgepole pine growth was slow and stands were heavily infected with dwarf mistletoe (*Arceuthobium americanum*

Nutt. ex Engelm.) and comandra blister rust (*Cronartium comandrae* Pk.) (Rasmussen 1987). Treatments consisted of three levels of diameter limit cuts and a spaced thinning. In addition, tree growth response, tree vigor, and regeneration were studied.

METHODS

The study area lies primarily in the East Long Creek drainage west of Dubois, WY, on the Shoshone National Forest. The elevation ranges from 7,600 to 8,800 ft, the lower half of the forested zone in the Wind River drainage. The climate is cool and dry; moisture availability is the most limiting growth factor during the season. Cole and others (1983) outline details of the study site, such as soils, habitat types, and stand characteristics before installation of treatments. Site index values for lodgepole pine in this area are 30 to 50 ft in 50 years.

Treatments consisted of two partial cuttings, one of which had three levels, and unthinned checks. These were randomly assigned to stands. Partial cutting began in January 1979 and was completed in February 1981. Treatments that we intended to test were one level of spaced thinning that was to leave the best 100 trees per acre as judged by size, form, and crown (two stands); and three levels of diameter limit cuttings and spaced thinnings. However, time constraints precluded sampling all initially selected stands. Therefore, several stands among each treatment were selected at random for surveying. These were:

Five of original 10 stands in the 7-inch diameter limit cuts

Nine of 17 stands in the 10-inch diameter limit cuts

Two of two stands in the 12-inch diameter limit cuts

Two of two stands in the spaced thinnings

Two check stands

Average diameter of trees in the 7-inch cuts averaged 7.6 inches d.b.h., the lower end of the 8-inch diameter class. Therefore, some trees in the stands were larger than the 7-inch class. The spaced thinnings contained about 50 trees per acre rather than 100 following thinning.

Using a double sampling scheme, stands were sampled in the fall of 1985, 5 years after the partial cuts were made, to obtain estimates of living and infested trees. Variable plots (10 BA factor) were used to sample green stand structure. The plots were 5 chains apart and were located in a grid pattern. The number of plots per stand was proportional to stand size and ranged from two to 10 per stand. An angle gauge was used to determine trees to be tallied. The diameter of all trees 5 inches d.b.h. and larger was measured, and trees were categorized as live, killed by MPB, or killed by other causes. The two live trees closest to plot center were measured for height and crown length, and two increment cores 180 degrees apart were taken from each for determining age and obtaining vigor measurements. A strip survey 1 chain wide was used to sample trees killed by MPB. All dead trees on the strip were tallied by cause of death, and the same measurements taken as on live trees in the variable plots. Study data were also used to evaluate performance in managed stands of the Cole and McGregor (1983) model developed for predicting tree losses to MPB in unmanaged stands.

From 1980 to 1985, d.b.h. and two measures of tree vigor—periodic growth ratio and grams of stemwood produced per square meter of foliage—were evaluated for change. In addition, leaf area was included to aid in interpretation of findings. Because so few lodgepole pines were killed by MPB, an extensive comparison of infested and uninfested trees such as that done by Amman and others (1988) was not possible. Therefore, tree size and vigor for live trees were compared between 1981 and 1985 and among treatments.

Vigor of trees was based on two measurements. One is growth efficiency expressed as grams of stemwood produced per unit of foliage (Waring and others 1980). Foliage is estimated from sapwood area: 1 inch^2 sapwood equals 1.16 yd^2 of foliage (Waring and others 1982). The second is periodic growth ratio (PGR), which is the current 5 years' radial stem growth divided by the previous 5 years' radial stem growth (Mahoney 1978). Regeneration plots for seedlings and saplings consisted of 1/100-acre plots, using the same center as each variable plot. All trees >1 inch d.b.h. were tallied by species.

Analysis of variance (ANOVA) (SAS procedure GLM for unequal numbers of observations) was used to analyze growth and tree vigor data among treatments and between years within treatments. Covariance analysis was included to analyze radial growth before (the covariate) with growth after treatment. Tukey's Studentized Range Test was used to test for significant differences ($P < 0.05$) among means.

RESULTS AND DISCUSSION

All stands in 1985 had average diameters of close to or exceeding the 8-inch average specified for stand susceptibility to MPB infestation (Amman and others 1977; Safranyik and others 1974). However, tree losses to MPB among treatments were significantly greater in check stands than all other treatments. Tree mortality did not differ significantly among the partial cutting treatments ($P > 0.05$).

Tree Losses to Mountain Pine Beetle

Five years after cutting, check stands had sustained 26.5 percent lodgepole mortality, the largest increase occurring in 1985. Tree mortality in treated stands ranged from 0.3 percent in the spaced thinnings to 7.4 percent in the 12-inch diameter limit cut (table 1; fig. 1). Thus, partial cutting appears to be highly effective in reducing losses to MPB. Although losses among treatments did not differ significantly, the trend is for greater losses where cutting was less.

Table 1—Lodgepole pine mortality caused by mountain pine beetles in partial cutting treatments, East Long Creek, Shoshone National Forest, WY

Treatment	Year							1979 to 1985	1981 to 1985	Percent killed 1981-85
	1979	1980[1]	1981	1982[2]	1983	1984	1985			
	- Trees per acre -									
7-inch	0.72	0.51	0.09	0.04	0	0.50	0	1.86	0.63	1.8
10-inch	.35	.66	.07	.20	.33	.85	.62	3.08	2.07	2.4
12-inch	.19	5.00	1.15	.74	.33	.67	.17	8.25	3.06	7.4
Spaced	.20	.10	.10	0	0	0	0	.30	.10	.3
Check	2.53	5.77	4.23	3.74	3.25	2.75	9.50	31.77	23.47	26.5

[1]Partial cuts were made in 1979 and 1980.
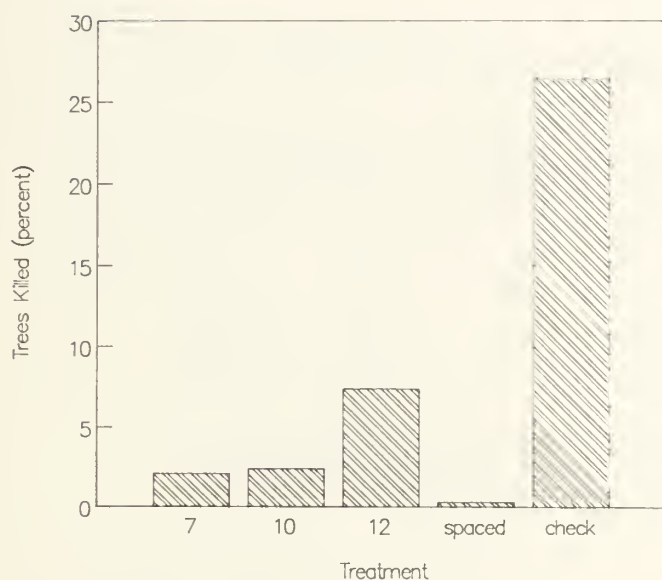[2]Estimated by using the average of 1981 and 1983.

Figure 1—Lodgepole pine losses to mountain pine beetle during 1981 to 1985, the 5 years after partial cutting treatments were applied, Shoshone National Forest, WY.

Table 2—Actual and predicted annual lodgepole pine mortality per acre to mountain pine beetle for the first 5 years following partial cutting treatments, East Long Creek, Shoshone National Forest, WY, 1985

Treatment	Annual loss		Actual as a percentage of predicted annual loss
	Predicted	Actual	
	- - Trees per acre - -		
7-inch	2.50	0.13	5.2
10-inch	2.40	.41	17.1
12-inch	4.40	.61	13.9
Spaced	.70	.02	2.9
Check	12.90	4.69	36.4

Annual tree mortality (trees per acre per year) from MPB predicted by the Cole and McGregor model (1983) (table 2) was substantially greater than actual loss in all treatments. Annual tree mortality in the check stands averaged 4.69 trees per acre compared to predicted losses of 12.90 trees per acre, or about 36 percent of predicted losses. The difference between predicted and actual losses is inversely proportional to the intensity of partial cutting. The Cole and McGregor (1983) model was developed for unmanaged lodgepole pine stands at lower elevations in Montana. Therefore, the difference between actual and predicted mortality values on the Shoshone National Forest probably is related to treatment effects and, in the case of check stands, the relatively high elevation of the stands for that latitude (7,600 to 8,800 ft). Hence, the stands are not as susceptible as lower elevation stands (Amman and others 1977). In addition, heavy dwarf mistletoe infection in the stands (Rasmussen 1987) may have reduced tree vigor and resulted in phloem too thin to attract and support higher beetle populations. McGregor (1978) observed less loss of lodgepole pine to MPB as dwarf mistletoe infection increased in the Gallatin National Forest in southwestern Montana.

Characteristics of Residual Stands

Number of trees per acre for all species ranged between 46.3 in the spaced thinning to 104.6 in the 10-inch diameter limit cuts (table 3). A large percentage of the residual trees was lodgepole. The check stands still had 65 lodgepole pines per acre after losing over 30 lodgepole pines per acre to MPB. Although the 10-inch diameter limit cuts contain more trees than the checks, differences in mortality probably reflect the effects of opening up the treated stand. Changes in stand microclimate as a result of tree harvest (Bartos and Amman in press), as well as removal of some of the larger diameter trees, probably affected beetle behavior, as observed in partial cuts in Montana (Schmitz and others in press), resulting in reduced infestation.

Table 3—Average number of trees and basal area per acre (trees ≥5 inches d.b.h.) in partial cut stands by tree species and treatment, East Long Creek, Shoshone National Forest, WY, 1985

| Treatment | Tree species | | | | | Total all species | Basal area | | Lodgepole d.b.h. |
	Lodgepole pine	Limber pine	Subalpine fir	Douglas-fir	Aspen		$\bar{x}$	sd	
7-inch	34.4	3.7	17.9			56.0	21.9	13.7	8.0
10-inch	84.7	6.6	1.1	2.9	9.3	104.6	41.1	17.1	8.6
12-inch	38.2	15.5	6.7	1.8	12.7	74.9	32.4	6.2	7.9
Spaced	37.4		8.9			46.3	35.0	7.1	10.5
Check	65.0	8.0	2.7		3.8	79.5	42.0	5.7	11.2

Posttreatment basal areas per acre of all species (1985) ranged from about 22 ft² BA for the 7-inch diameter limit cuts to 42 ft² BA for the checks (table 3). Basal areas were light even for the check stands. The most consistent difference among treatments was in tree diameter. Average d.b.h. of lodgepole in the check was significantly larger ($P < 0.05$) ($\bar{x} = 11.2$ inches) than all other treatments. Trees in the spaced thinning had the second largest diameters ($\bar{x} = 10.5$ inches) (table 3).

In the diameter limit cuts, d.b.h of trees, which ranged between 7.9 and 8.6 inches, did not differ significantly ($P > 0.05$). The large diameter of trees in the check stands probably is a significant factor in the continued infestation in those stands. Diameter was found to be an important factor in susceptibility of lodgepole to infestation in natural stands (Cole and Amman 1969; Stuart 1984), as well as in partially cut stands on the Kootenai and Lolo National Forests (Amman and others 1988). However, the fact that the spaced thinnings had average d.b.h. almost as large as the check stands points to the probable role of microclimate in reducing losses to MPB in thinnings (Bartos and Amman in press).

Growth Response

ANOVA revealed a significant difference in growth among stands before the treatments were applied ($P < 0.05$). For the 1976 to 1979 period, the treatments tended to separate (Tukey's Studentized Range Test) into two groups significant from one another. An exception was the 10-inch diameter limit cut that appeared in both groups. Group 1 consisted of the 7-inch and 10-inch treatments, and group 2 consisted of the check, 10-inch, 12-inch, and spaced thinnings.

Following treatment, growth response was significantly different among treatments ($P < 0.05$), with the covariate (radial growth before treatment) also significant ($P < 0.05$) (fig. 2). Growth following treatment also separated into two significantly different groups. Group 1 consisted of the 12-inch diameter limit cuts and spaced thinnings. Group 2 consisted of the 7-inch and 10-inch diameter limit cuts, and check stands (table 4). Trees in all treatments had substantial live crowns with averages ranging between 46 and 63 percent of total tree height
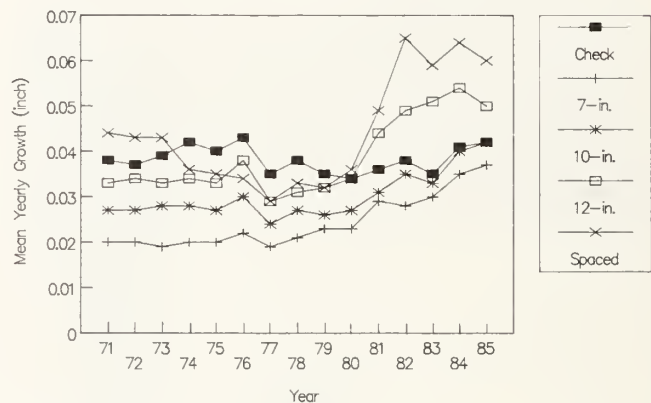

Figure 2—Radial growth of lodgepole pine before (1971 to 1980) and after (1981 to 1985) partial cutting treatments, East Long Creek, Shoshone National Forest, WY.

(table 4). Therefore, trees had ample capacity to respond with increased growth following thinning. Only the check stands did not respond with a significant increase in growth ($P > 0.05$); however, the trend is up. Apparently, increases in numbers of trees killed by MPB were not large enough to provide growth response as rapid as partial cutting treatments, even though crown ratios in the check stands were similar to those of residual trees in the partial cut stands. Extensive tree mortality in check stands in the Kootenai and Lolo resulted in significant growth response of residual trees (Amman and others 1988).

Regeneration

Regeneration averages ranged from 1,160 trees per acre in the 12-inch diameter limit cuts to 3,650 trees per acre in the spaced thinnings (table 5). The pine species were generally more abundant in the spacing, 7-inch and 10-inch diameter limit cuts. The more tolerant conifers (Douglas-fir, subalpine fir, and spruce) were more abundant than pine in the 12-inch and check treatments. Figure 3 shows the relationship between treatment and tolerance of regenerated species, excluding aspen. (The check unit contained more aspen inclusions initially than

Table 4—Radial stem growth of lodgepole pine, before and after partial cutting treatments, and percent live crown, Shoshone National Forest, WY

Treatment	Growth				Live crown
	1976 to 1979		1982 to 1985		
	Total	Average annual	Total	Average annual	
	Inches				Percent
7-inch	0.083 a[1]	0.021	0.127 a	0.032	46.5
10-inch	.100 a,b	.025	.146 a	.037	54.8
12-inch	.127 b	.032	.200 b	.050	63.4
Spaced	.129 b	.032	.248 b	.062	51.1
Check	.129 b	.032	.138 a	.035	60.6

[1]Averages within a column followed by the same letter are not significantly different; those followed by different letters are significantly different, α 0.05.

Table 5—Regeneration (trees <1 inch d.b.h.) by tree species in partial cut stands, East Long Creek, Shoshone National Forest, WY, 1985

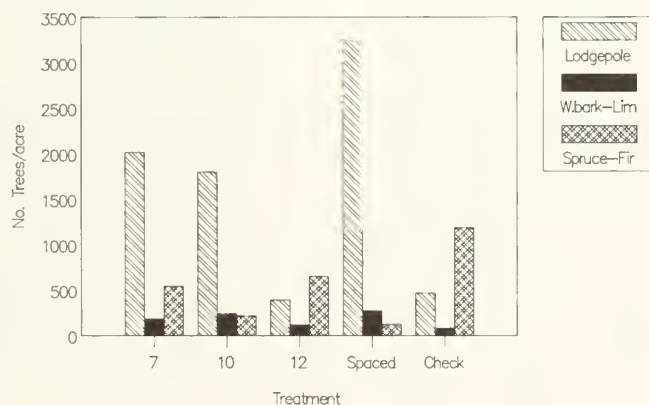| Treatment	Lodgepole pine	Limber and whitebark pine	Aspen	Douglas-fir	Spruce	Subalpine fir	Total
	Trees per acre						
7-inch	2,014	186	0	0	6	537	2,743
10-inch	1,796	243	8	33	41	143	2,264
12-inch	390	120	0	350	0	300	1,160
Spaced	3,250	275	0	0	0	125	3,650
Check	468	84	853	105	126	953	2,589

Figure 3—Regeneration of shade-tolerant and intolerant species per acre (all trees 1 inch d.b.h.) 5 years after stands received partial cutting treatments, East Long Creek, Shoshone National Forest, WY, 1985.

the treated units. (Openings caused by the mountain pine beetle could stimulate root suckering in aspen.) In all cases, adequate numbers of seedlings and saplings are available for the next stand, should the manager decide to do an overstory removal at this time. Most regeneration is too short to provide hiding and thermal cover for big game. However, there is a tradeoff between big game cover and health of the next stand. Because of the heavy dwarf mistletoe infection, removal of the overstory at this time would prevent extensive infection of the regeneration.

Tree Vigor

ANOVA of change in d.b.h. between 1980 and 1985 shows a significant difference among treatments ($P < 0.05$). Tukey's Studentized Range Test shows no significant difference among means for the check, 7-inch, and 10-inch diameter limit cuts, and no difference between means for the 12-inch diameter limit and spaced thinnings ($P > 0.05$). However, the two groups of thinnings differed significantly ($P < 0.05$). These changes ranged between an average of 0.31 inch in the 7-inch diameter limit cuts to 0.59 inch in the spaced thinnings. As expected, the largest gains in growth occurred in the stands that were thinned substantially, but that also left many of the dominant and codominant trees in the residual stands.

For 1980, PGR's did not differ significantly among treatments ($P > 0.05$). However, large changes occurred by 1985. Only the PGR's for the unthinned check stands were significantly less than those of other treatments ($P < 0.05$). PGR's were significantly greater ($P < 0.002$) in 1985 than 1980 for all treatments except the check and 10-inch diameter limit cuts ($P \geq 0.09$). PGR's in 1985 ranged between 1.13 for the checks and 1.74 for the spaced thinnings, in contrast to a range between 1.02 for the spaced thinning and 1.25 for the 10-inch diameter limit cuts in 1980 (table 6).

Increase in PGR in a stand is indicative of increasing tree vigor. Average PGR's exceeding 1.00 for all treatments both in 1980 and 1985 suggest that all stands were resistant to infestation by MPB. The dividing point between susceptible stands and those resistant to MPB is 0.9 (Mahoney 1978). PGR's for trees killed by MPB in the check stand averaged 0.9, and the trees killed in the spaced thinning had a PGR of 1.1. Therefore, even the check stands should have been resistant to MPB. However, MPB continued to kill trees at an increasing rate during the past 5 years.

Grams of wood per square meter of foliage in 1980 were significantly different ($P < 0.05$) among treatments. Tukey's test identified only two differences: check ($\bar{x} = 54.7$ g) compared to 12-inch diameter limit cuts ($\bar{x} = 47.0$ g), and 7-inch diameter limit cuts ($\bar{x} = 56.3$ g) compared to the 12-inch diameter limit cuts. Because grams of stemwood per square meter of foliage and leaf area were significantly different in 1980, a covariance analysis of data obtained in 1985 would have been appropriate to account for these 1980 differences. However, data were obtained in different sets of trees in 1980 and 1985. Therefore, a covariance analysis was deemed inappropriate. One-way ANOVA between 1980 and 1985 data was used to determine if significant changes had occurred within treatments but not between treatments. ANOVA between years showed only the 12-inch diameter limit

Table 6—Diameter at breast height, grams of stemwood per square meter of foliage, periodic growth ratio, and leaf area in 1980 and 1985 for residual trees in lodgepole pine stands receiving different partial cutting treatments, East Long Creek, Shoshone National Forest, WY

| | Number of observations | | Diameter at breast height (inches) | | | | | | Grams of wood | | | | |
| | | | 1980 | | 1985 | | | | 1980 | | 1985 | | |
Treatment	1980	1985	$\bar{x}$	sd	$\bar{x}$	sd	$P > F$		$\bar{x}$	sd	$\bar{x}$	sd	$P > F$
7-inch	22	90	7.6a[1]	1.92	8.0a[1]	1.89	[2]0.001		56.3a[1]	79.0	59.1	37.7	[2]0.808
10-inch	46	132	8.3a	1.90	8.6a	1.88	.001		69.8ab	57.2	57.1	36.4	.083
12-inch	36	38	7.4a	1.97	7.9a	1.86	.001		47.0a	21.2	68.6	41.1	.006
Spaced	34	14	9.9b	2.49	10.5b	2.44	.001		68.1ab	29.2	70.1	41.3	.850
Check	45	34	10.9ab	2.06	11.2b	2.11	.001		54.7a	52.8	63.3	37.6	.420

| | Periodic growth ratio | | | | | Leaf area (m²) | | | | |
| | 1980 | | 1985 | | | 1980 | | 1985 | | |
Treatment	$\bar{x}$	sd	$\bar{x}$	sd	$P > F$	$\bar{x}$	sd	$\bar{x}$	sd	$P > F$
7-inch	1.03a[1]	0.33	1.59a[1]	0.81	[2]0.002	26.3a[1]	12.8	27.8	14.8	[2]0.665
10-inch	1.25a	.62	1.45a	.72	.088	26.6a	11.7	36.1	18.1	.001
12-inch	1.04a	.33	1.44a	.57	.001	39.7c	13.0	31.0	15.0	.009
Spaced	1.02a	.28	1.74a	.75	.001	41.7b	22.9	55.1	31.1	.106
Check	1.07a	.65	1.13b	.36	.655	49.5b	29.4	50.6	24.3	.853

[1]ANOVA was used to compare treatments by year.
[2]One-way ANOVA used between years by treatment.

cuts had a significant change in stemwood production per unit of foliage (1980 $\bar{x}$ = 47.0; 1985 $\bar{x}$ = 68.6).

These results suggest that changes in stemwood production per unit of foliage are slow. Even though wood production per unit of foliage did not differ among the check, 7-inch, and 10-inch treatments, only the check showed an increase in mortality to MPB. Therefore, wood production per unit of foliage does not appear to reflect very well the substantial increase in stem growth. This is perplexing, because the calculations should be highly sensitive to changes in width of the most recent growth ring. One possibility is that rings being dropped from the inner part of the sapwood and added to heartwood have area similar to the most recent outside ring added to the sapwood, thereby maintaining a fairly constant wood production per unit of sapwood (equivalent to foliage). Support for this idea is furnished by comparisons of leaf area measurements for 1980 and 1985.

ANOVA showed that significant differences ($P < 0.05$) in leaf area occurred only in the 10-inch diameter limit cuts (1980 $\bar{x}$ = 26.6 m²; 1985 $\bar{x}$ = 36.1 m²) and the 12-inch diameter limit cuts (1980 $\bar{x}$ = 39.8 m²; 1985 $\bar{x}$ = 31.0 m²) (table 6). In the 10-inch diameter limit cuts, leaf area increased but wood production decreased. This is consistent with the scenario that root growth increases first, followed by crown, and finally by stemwood (Waring 1983). However, in the 12-inch diameter limit cuts, the opposite occurred: leaf area showed a decline but stemwood increased. The 12-inch diameter limit cut was opened up more than the 10-inch diameter limit cut, as indicated by residual stocking. Possibly a greater loss of shade needles occurred, accompanied by a corresponding reduction in sapwood area in the 12-inch cut. This would have shifted the area ratio of current radial growth to sapwood area so that more wood per unit of foliage was produced in 1985 than in 1980.

On a stand basis, d.b.h. and vigor measurements do not account for differences in tree mortality. The average d.b.h. of the check stands is not significantly larger than that of the spaced thinnings, which suffered little or no loss. PGR, while less in the check than in other treatments, was still above 1.00. Wood production per leaf area unit in check stands was intermediate among treatments, while leaf area was among the highest. We suspect that change in microclimate of partial cut stands is a contributing factor (as Amman and others [1988] also hypothesized) for loss differences observed in thinnings on the Kootenai and Lolo National Forests. In the Kootenai and Lolo stands, changes in tree vigor as measured by PGR and grams of wood did not account for differences in tree mortality between thinned and unthinned stands. In the Kootenai and Lolo thinnings, large numbers of beetles were trapped in passive barrier traps, indicating many beetles were flying in the stands but few were infesting trees (Schmitz and others in press). The large beetle populations on the Kootenai and Lolo compared to the Shoshone, as indicated by tree mortality in the check stands (Kootenai = 93.8 percent; Lolo = 73.4 percent; Shoshone = 31.8 percent), showed that partial cuts were effective even when subjected to large beetle populations. At the same time, vigor ratings of residual trees indicated the stands were still highly susceptible to beetle infestation.

CONCLUSIONS

1. Partial cutting lodgepole pine stands significantly reduced lodgepole pine losses to mountain pine beetles.

2. Residual trees in thinned stands responded with a significant increase in diameter growth.

3. Regeneration 5 years after thinning was adequate for overstory removal.

4. Both thinned and unthinned stands remained susceptible to MPB infestation based on diameter and vigor ratings of residual trees.

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Lodgepole pine stands were thinned in the Shoshone National Forest of northwestern
Wyoming in 1979 and 1980 using different forms of partial cutting. Average losses of
trees 5 inches diameter at breast height and larger to mountain pine beetles during the
5 years following thinning ranged from less than 1 percent in spaced thinnings to 7.4 per-
cent in the 12-inch diameter limit cut, compared to 26.5 percent in check stands. Residual
trees increased radial growth significantly, but change in growth efficiency is slow. Regen-
eration 5 years after thinning ranged between 1,160 and 3,560 seedlings per acre, with
pine being favored in the more open stands.

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